Integration and Test of a 2nd Generation Dual Purpose Pulse Forming Network into the P&E HWIL SIL

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ABSTRACT

A 2nd Generation Dual Purpose Pulse Forming Network (DP-PFN) has been developed to power both the Electro-Thermal-Chemical (ETC)/Electro-Thermal-Ignition (ETI) lethality capability and the Electro-Magnetic Armor (EMA) survivability capability improvements envisioned for future hybrid-electric vehicles. ETI decreases the ignition variability associated with the launching of conventional munitions by roughly a factor of ten which, in conjunction with the systems ballistic computer, greatly enhances hit probability of the round. ETC provides maximum performance in all conditions, including temperature compensation, resulting in increased lethality and range with higher average muzzle velocities. EMA uses stored electric energy to disrupt a shaped-charge jet and reduce it's depth of penetration.

The second generation DP-PFN for driving both ETI/ETC and EMA emulators is scheduled to be integrated into the Power and Energy (P&E) Hardware-in-the-Loop (HWIL) System Integration laboratory (SIL) in Santa Clara, California in 2006. The DP-PFN is capable of providing either the short pulse lengths required by the EMA or the considerably longer pulse lengths required by the ETI/ ETC Gun as well as emulating various "degraded functionality" states such as loss of individual capacitors. Integration of this DP-PFN marks another great milestone for the SIL, ensuring that it continues to be capable of emulating all the major hybrid-electric mobility functions of a ground combat vehicle as well as the major lethality and survivability electrical loads. This paper describes the DP-PFN components, the overall DP-PFN design philosophy and the planned integration and testing of the DP-PFN in the P&E HWIL SIL.

1   INTRODUCTION

The Army's Pulse Power for Future Combat System (FCS) Army Technology Objective (ATO) program provides enabling technologies for revolutionary FCS survivability and lethality solutions including Electro Magnetic Armor (EMA), Electro-Thermal Chemical (ETC) Gun, High Action/Fast Rise-Time Switches for EM Gun and a Pulse Forming Network (PFN) for the Solid State Heat Capacity Laser (SSHCL). The Pulse Power ATO focuses on accelerating the

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development of emerging power technologies that will provide dramatic reductions in the weight and volume of pulse power components. This is done in parallel with advancements in the associated technologies (i.e. EM Gun, EMA, etc.) in order to drastically reduce the development time associated with maturing these technologies. One of the major deliverable components developed under this ATO are High Energy Density (HED), Dual Purpose (DP) Pulse Forming Networks (PFNs) that are capable of providing the intermediate energy storage and pulse shaping required for both EMA and ETC loads.

2 DUAL PURPOSE PFN (DP-PFN)

Three "generations" of DP-PFNs are planned in the Pulse Power for (FCS) ATO, each representing a significant technological advance over its predecessor. The first generation PFN resulted from a joint Army-DARPA effort in the original Combat Hybrid Power System (CHPS) program [1],[2], [3], [4] and has been described previously [5].

2.1 FIRST GENERATION

The first generation PFN, which is currently in the SIL, is equipped with two subsystems that can provide 100kJ each, PFN1 and PFN2. Both subsystems fire for the EMA load, whereas only one subsystem fires for the ETC load. A 10^{-9} Torr triggered vacuum switch (TVS) is set up for firing the PFN into the ETC load. design philosophy. The second1 shows a picture of the PFN set up in the SIL.

Figure 1: First Generation DP-PFN

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2.2   SECOND GENERATION

The second generation PFN utilizes advances in pulsed power technology not available at the time the first generation PFN was built, it incorporates lessons learned from experience gained while operating the PGN generation one and amends the design philosophy. The second generation PFN has a faster charging system, solid state high current switches, higher energy density capacitors, and an improved controller. Observations of unexpected failure conditions, high voltage breakdown, field effects of high current, grounding and shielding issues and controls failures have been addressed in the second generation. Maintenance issues and new applications have lead to an update in the design philosophy; there is added emphasis on accessibility and configurability. The PFN is configured for the SIL, but is designed to easily be reconfigured. The Second Generation DP-PFN is shown in Figure 2 below.
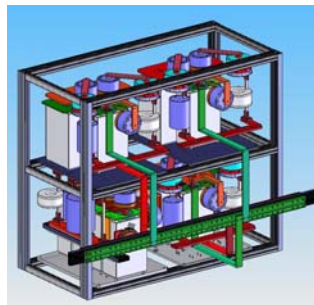

Figure 2: Second Generation DP-PFN

The ETC gun loads and the EMA loads have different power requirements. The ETC gun requires longer duration and lower peak current pulses than the EMA load. The EMA load requires shorter duration and higher current pulses on than the ETC load. ETC provides high muzzle velocities resulting in enhanced range and lethality. In addition ETC provides significant propellant improvement performance at low temperatures (below -40°C). EMA reduces the depth of penetration from a shaped charge jet munition by using stored electric energy to disrupt

it. A shorting circuit is formed between two parallel armor plates and through the jet upon the jet's impact into the armor. The resulting extremely high current heats up the jet and induces magneto-hydrodynamic instabilities which cause the jet to particulate and form "smoke rings". The residual armor penetration is thus drastically reduced.

The PFN has two basic modules and two supporting pieces. The two basic modules are the Bulk and Shaping modules. Each bulk module produces a pulse with the full pulse length of the output pulse. The schematic of the bulk module can be seen in Figure 3. Each bulk module contains four capacitors in parallel. Two switches with series inductors are attached to the capacitor bank. The switches allow for inductor selection during firing and can be fired individually or in parallel. Three possible output pulses can originate from each bulk module (inductor A, inductor B, inductors A & B in parallel). Diodes are in parallel with the capacitors to prevent voltage reversal on the bank (reversal will reduce capacitor lifetime). A fault protection diode is also included on the output of the bank. This protects the system in case of a short in the capacitor. The shaping module has four parts; each part has a series capacitor, diode and inductor (see Figure 3). One switch fires the shaping module. Similar to the bulk module, diodes for voltage reversal protection and fault protection are included. The shaping module is intended to create the initial rise time of the pulse and maintain the current levels until the bulk modules take over.
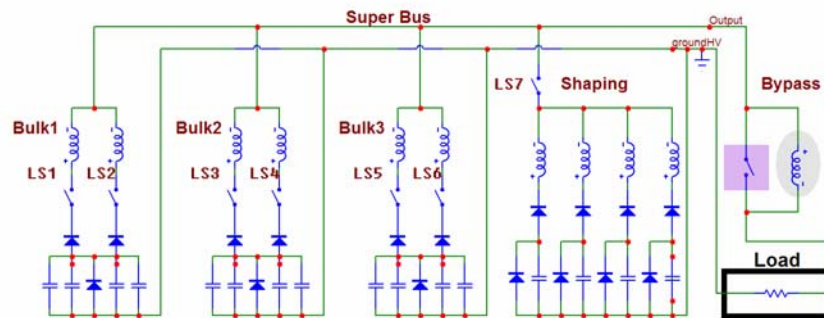

Figure 3: System Schematic

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The shaping module has the lowest inductance bus system (< 50 nH) and requires the most consideration when choosing inductor values. The bus inductance for the bulk modules is higher (< 200 nH) but is smaller than typical bulk module inductor values (500 nH to 10 µH). The inductors are simply sized down to match the desired overall inductance.

To select the ETC or the EMA mode of operation a bypass circuit has been included on the output of the system. The bypass adds a negligible inductance to the circuit (< 50 nH). If only EMA pulses are desired, the bypass switch is closed and the inductor is shorted. If only ETC pulses are desired the bypass switch is closed and the ETC inductor is included in the PFN ETC circuit.

The PFN is currently configured to generate three pulses. Two pulses are for EMA and one for ETC. The transition from EMA to ETC or vice versa takes less than two seconds. The repetition rate of the PFN is primarily determined by charging capabilities. The SIL configuration allows for five shots in ten seconds.

2.3   DEGRADED FUNCTIONALITY EMULATION

The ability simulate degraded functionality allows for testing problematic situations before they occur in the field. The condition most likely to occur is capacitor loss.

Capacitor loss can be simulated multiple ways: physical removal of the capacitor, by not charging the capacitor or simply not firing the switch associated with the capacitor. The PFN is designed to easily remove capacitors in a minimal period of time. With basic technical ability, physically removing any capacitor or group of capacitors takes less than an hour. The controls are capable of selecting if individual bulk module is charged and which individual caps in the shaping module are charged. By not charging the caps, you can see the effects of a failed capacitor in the system. The fault protection diodes on the output of each capacitor are capable

of isolating a dead bulk module or individual capacitor in the shaping module. The system will still function with a short in one of the capacitors. The last method for simulating capacitor loss is to simply not fire the switch associated with the loss. The resultant waveforms generated by the PFN will effectively show the PFN's response to capacitor loss.

3   COMPONENTS

3.1   MAIN COMPONENTS

3.1.1 Capacitors

The High Energy Density Capacitors in the DP-PFN are 12.5 kJ Bi-axial-Oriented Poly-Propylene (BOPP) built by ICAR. They are designated as "Design 1" and are shown below along with their major performance specifications in Figure 4.

Design 1 Capacitors by ICAR

- 258 µF
- 12.5 kV
- 13.5kJ @ 12 kV
- ESR of 5mΩ
- ESL of 40nH
- 1.6J/cc

Figure 4: ICAR Design 1 Capacitors

3.1.2 Inductors

The dual purpose PFN utilizes ten total inductors with six different values of 250, 500, 1600, 4500, 7000, and 15000 nH. Five of these inductor values are needed in the bulk and shaping modules, with the sixth and largest value in the output module. Two separate inductor designs are used in the PFN: helical inductors for the three smallest values and concentric ring inductors for the three largest. These two inductor types are shown below in Figure 5.
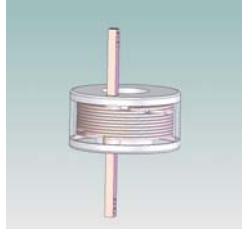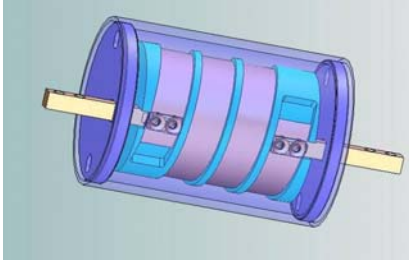
Figure5: Helical and Co-axial Inductors

3.1.3 OptiSwitch Light Activated Solid State (LASS) Switches

The DP-PFN uses all solid-state switching based on an asymmetrical thyristor with an integrated anti-parallel diode. The switch is activated with a fiber coupled semiconductor laser diode array and utilizes standard 5V TTL input triggers. The switches have been designed to provide a blocking voltage of 13kV and to handle a peak current of 150kA with a di/dt of 50kA/µs and action of 3.8M A^2s. It is shown in Figure 6 below.
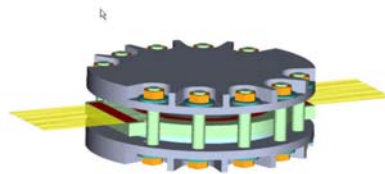

Figure 6: Opti-Switch

3.1.4 Low Inductance Configurable Bus

The PFN bus is shown in Figure 7. Hot and return are kept as close as possible to decrease the inductance of the bus, which is 3 nH/ft.

Figure 7: Super Bus

3.1.5 Bypass

The output module, shown below in Figure 8, allows for selection between the EMA and ETC pulses and interface with the dynamic load. This module contains the mechanical disconnect and the 15000 nH inductor. When the disconnect is open, the only current path is through the inductor to the dynamic load. When the disconnect is closed, there is a short across the inductor, so virtually all of the current will take the now shorter path to the dynamic load.
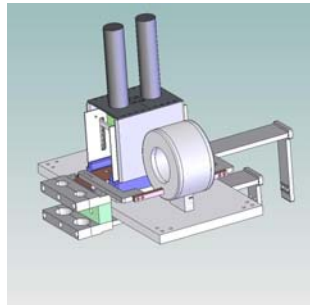

Figure 8: ETC Bypass

3.2   SatCon DC/DC Converter

The DP-PFN is charged using a high-power-density SatCon DC/DC converter measuring 24" X 23" X 4.5" shown in Figure 9 below. The system has an output power of 175 kW/300 kWpk and an output voltage of 10 kVDC with a nominal input voltage of 610 VDC. It is capable of charging a 300 kJ bank with a duty cycle of 2 sec charge +500 us rest.

Figure 9: SatCon converter

3.3　Control System

One of the goals of the control system is to maximize all isolation between the control system and the PFN. One of the ways that this has been incorporated into the control system design is to use fibers to transmit and receive all possible discrete signals. These discretes include contactor commands and status monitors, and also charger commands and status monitors.

At the load side, each load device, *e.g.* contactor or charger, has a dedicated interface assembly. Each assembly is AC powered, and can be connected via an isolation transformer. This way, each load device is isolated from other devices as well as from the main controller itself. The present design baseline for the PFN system requires 9 contactors to manage the PFN charge, 5 contactors to determine the ETC load status, and additional lines to operate the charger. This translates into 26 individual discrete inputs or outputs to operate the load devices. The Control software was developed using COTS Auto-coding software. Figure 10 illustrates the Control System Architecture.
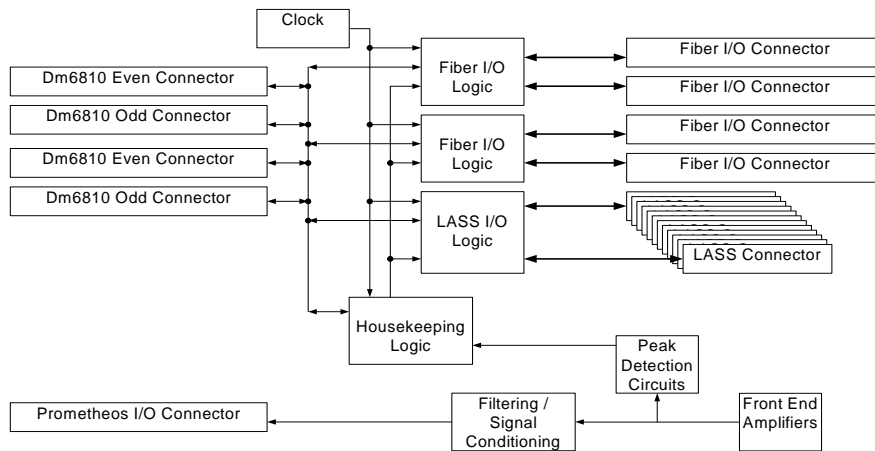
Figure 10: Control System Architecture

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4 Conclusion

The design of the Second Generation Dual Purpose PFN is another milestone for the SIL. The DP-PFN provides the SIL with the capability to emulate the major hybrid-electric mobility, lethality, and survivability functions of future hybrid-electric ground vehicles. The DP-PFN provides an array of waveforms and is designed to accommodate new and changing waveform requirements. The DP-PFN provides a broader testing capability for the SIL and advances PFN technology significantly.

5 Acknowledgements

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